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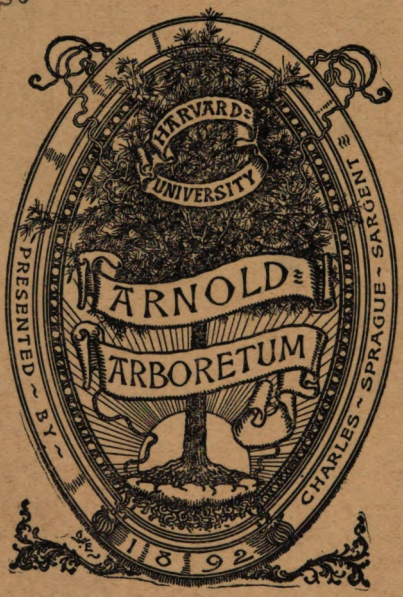

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SOIL AND SITUATION

IN RELATION TO

FOREST GROWTH.

BY

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SOIL AND SITUATION IN RELATION TO FOREST GROWTH.

It may be remarked at the outset that much of the following information has been compiled from German sylvicultural works, more especially from Ramann's "*Forstliche Standortslehre*" in Lorey's "*Handbuch der Forstwissenschaft*," 1886, Grebe's "*Gebirgskunde, Bodenkunde, und Klimalehre, in ihrer Anwendung an Forstwirthschaft*," 4th edition, 1886, Gayer's "*Waldbau*," 3rd edition, 1889, and other works specially quoted.

It treats of a subject not strictly falling under any of the four main branches of forestry,—Sylviculture, Protection of Forests, Utilisation of Forest Produce, and Management of Forests,—but concerning which it is at the same time necessary that the forester should have a certain degree of sound knowledge.

I.—Soil in relation to Forest Growth.

Soil is the name given to the product of the decomposition of the rocks forming the crust of the earth. By reason of its permeability and of its other physical properties, it enables trees to obtain support and food-supplies by means of their roots and rootlets. Although woody-fibrous plants derive by far the greatest portion of their nourishment from the carbonic acid (CO_2) contained in the air, yet certain necessary substances are obtainable only from the soil, and the development of forest growth is stimulated when the soil is rich in these mineral substances in forms capable of being taken up by the root-system. The finer and usually most decomposed earth forming the upper layer, and often varying greatly in depth, is called the *soil* or *surface-soil*, from which timber trees draw most of their mineral nutriment; below this is the *subsoil*, which may, or may not, be of the same composition as the soil. The external signs of shallowness of soil are outcrop of stone, inordinate development of the root-system, and inferior development of stem; those of depth of soil are length of bole and good development in height, with richer growth of underwood, brushwood, and weeds to form a soil-covering.

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1. *The Chemical Composition of Soils* is in so far of importance to tree-growth that if different kinds of wood be reduced by combustion the ashes will invariably show certain chemical constituents which are absolutely requisite for the formation of the ligneous structure, viz. :—Potash, calcium, magnesia, iron, phosphorus, and sulphur. Each of these necessary foods must be present in sufficient quantity in the soil before plants can find the conditions suitable for their growth and development. The functions performed by these different constituents are believed to be as follows :—

Potassium.—Assimilation, transformation of sap, and formation of starchy matter.

Calcium.—Formation of cell-walls in the cambium.

Magnesia, Phosphorus, and Sulphur.—Formation of albuminoid substances.

Iron.—Formation of chlorophyll in the leaves.

In addition to these the ashes of every plant yield soda and silica, often in very high percentage, whilst manganese and aluminium are also less frequently found.

Most soils yield a sufficient quantity of all these various constituents to enable tree-growth to be possible; they must, however, be held as *soluble salts* so as to be available in a form capable of being absorbed by the suction-rootlets.

In agriculture the productive capacity of land is to a great extent commensurate with the inorganic richness of the soil; but as tree-growth utilises comparatively very much smaller quantities of mineral constituents (especially of those less common) than are demanded by agricultural produce, the capability of any soil is not determinable by the quantity of inorganic matter available for food-supplies, except perhaps in the case of the very poorest classes of forest land.

The actual quantities of mineral substance annually utilised per acre, as found in the ashes of agricultural and forest produce, have beeen shown* to be as follows :—

Average of	Total Quantity of Ashes.	Silica, SiO_2.	Potash, K_2O.	Lime, CaO.	Magnesia, MgO.	Phosphoric Anhydride, P_2O_5.	Sulphuric Anhydride, SO_3.	Other Constituents.
Mixed agricultural produce.	235	37	78	43	17	28	11	21
Woodland growth, timber and leaves.	126	29	11	62	10	8	3	3
Woodland growth, timber only.	19	1·6	4	9	2	1·4	0·4	0·6
Approximate ratio of woodland to agricultural demand for mineral constituents.	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{7}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{2}{7}$	$\frac{1}{2}$	$\frac{1}{7}$

* Ebermayer's "*Physiologische Chemie der Pflanzen*," 1882, Vol. I., p. 761.

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With regard to the woodland growth, it is notable that the greatest deposits of mineral constituents are found in the leaves, where the preliminary processes take place for carrying out the work of assimilation, then in the bark active in depositing the transformed sap, and that in recently-formed sapwood and branches there is contained about double the quantity that is to be found in the duramen or old wood of the stem, where the total of ashes seldom exceeds 1 per cent.

Weber* gives the average analysis of the dry timber of different species of European forest trees as :—

50	per cent.	carbon.
42	„	oxygen.
6	„	hydrogen.
1	„	nitrogen.
1	„	ashes.
100		

As the total demand on mineral food-supplies made by woodland growth barely exceeds half of that made by agricultural produce, and as through the fall and decomposition of the leaves by far the greater portion of it is returned to the soil, it will be at once apparent that forests of normal density do not exhaust the soil to anything like the same extent as agricultural crops.

According to Prof. R. Hartig of Munich† :—

"The quantity of mineral food taken up from the soil depends chiefly on the species, for some plants extract greater supplies than others. Thus the spruce, for example, when growing along with the beech in forests, forming close canopy, extracts more raw mineral substance for ashes than the latter. At 50 years of age the relative proportion of production between the spruce and the beech is—

As regards cubic contents of timber - - -	2·78 to 1
As regards dry woody-fibrous tissue - -	1·80 to 1
As regards ashes (mineral substance) - -	1·28 to 1

These figures prove that spruce not only withdraws more nourishment from the soil than beech, but that it also produces more timber than the beech from any given quantity of mineral nutriment. For the production of any given cubic quantity of beech timber more mineral matter is requisite than for the production of the same volume of spruce."

The absolute demands of the various species of forest trees on the nutrient strength of the soil have not yet been determined, the difficulty being that the mineral constitution is not the only factor, but that all the physical qualities exert their influence under every circumstance, and in the most complicated concrete conditions. Hence their final expression is a resultant that cannot be fixed beforehand. Experience, however, shows that

* "*Aufgaben der Forstwirthschaft*" (Lorey's "*Handbuch*"), 1886, p. 72.

† "*Anatomie und Physiologie der Pflanzen*," 1891, p. 227.

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European forest trees may be classified as follows in regard to the demands made on the fertility of the soil :—

Decidedly exacting -	Elm, maple, sycamore, ash.
Exacting - -	Oak, beech, lime, silver fir.
Moderate - -	Sweet chesnut, larch, hornbeam, spruce, alder, aspen, willow.
Least exacting -	Birch, Scots, Austrian, and Weymouth pines.

The power of accommodating themselves to soils and situations not naturally suited to their growth and normal requirements is greatest in Scots pine and birch, less pronounced in oak, beech, spruce, and silver fir, and least of all in ash, elm, maple, and sycamore.

It is impossible to say that clayey, loamy, limy, or sandy soils are necessary for any particular species. Extracts from the works of the most eminent German sylviculturists are often absolutely contradictory on this point ; whilst G. Heyer,* on the other hand, even went so far as to assert that almost any soil could produce any kind of timber, provided it were supplied with the necessary and suitable quantity of moisture. Ney† summarises as follows :—

"As regards chemical composition of the soil, even slightly sour marshy soils are unfavourable to all species of trees except alder, birch, and spruce, whilst sour soils liable to dry up at certain seasons are unsuited for all except birch, spruce, Scots and Weymouth pines. Only these last-named species thrive on pure peat, and not even the spruce when it is dry. Ash, maple, sycamore, and elm require a moderate quantity of lime in the soil, and beech, hornbeam, oak, as also larch and black pine, thrive best on soils that have at least some lime in their composition. The hardwoods—oak, ash, maple, sycamore, elm, sweet chesnut, beech, and hornbeam—also appear to demand the presence of a considerable quantity of potash ; whilst, on the other hand, spruce, silver fir, and especially Scots pine and birch, thrive on soils rich neither in lime nor potash."

The primary rocks forming the bulk of the earth's solid body are for the most part made up of only eight elements, the remainder being found in much smaller quantities, as the following table‡ shows :—

Composition of the Earth's Crust in 100 parts by weight.			
Oxygen -	44·0 to 48·7	Calcium -	6·6 to 0·9
Silica -	22·8 to 36·2	Magnesium	2·7 to 0·1
Aluminium	9·9 to 6·1	Sodium -	2·4 to 2·5
Iron -	9·9 to 2·4	Potassium -	1·7 to 3·1

* "*Forstliche Bodenkunde und Klimatologie*," 1856, p. 488.
† "*Die Lehre vom Waldbau*," 1885, p. 64.
‡ Roscoe's "*Elementary Chemistry*," 1888, p. 8.

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Soils are composed for the most part of salts, together with oxides, and less frequently chlorides. These salts consist chiefly of silicates, often in combination with water, of carbonates, and sulphates, whilst phosphates are only of occasional occurrence, although of great importance to plant life. The most important of these constituents are:—Silica or silicon dioxide (SiO_2); carbonic acid or carbon dioxide (CO_2); sulphuric anhydride or sulphur trioxide (SO_3); phosphoric anhydride or phosphorus pentoxide (P_2O_5); water (H_2O); potassium monoxide (K_2O); sodium oxide (Na_2O); lime or calcium oxide (CaO); magnesia or magnesium oxide (MgO); ferrous oxide (FeO); sesqui-oxide of iron or ferric oxide (Fe_2O_3); alumina (Al_2O_3); and dioxide of manganese (MnO_2).

Among the silicates are included quartz, serpentine, talc, feldspars, mica, hornblende, augite, and chlorite. To the carbonates belong carbonate of lime, chalk, and dolomite, and to the sulphates anhydrite, and gypsum or calcium sulphate.

2. *The Formation of Soil* takes place partly by mechanical or physical, partly by chemical, and partly by organic means.

"Winds, frosts, and rains; springs, streams, and rivers; tides, waves, and currents; the shivering of the earthquake, and the upheaving of the volcano; the alternate growth and decay of plants and animals; and the universal operations of chemical agency,—are all continually tending to separate, to combine, and to re-arrange the materials composing the crust of the earth." *

The Physical Forces are dependent on temperature for their action. All bodies expand and contract with changes of temperature, and the tension or pressure in different layers of rocks may be influenced so much as to cause fissure, splitting, and cleavage. This is especially the case with rocks containing crystals not belonging to the regular system, for the varying expansion along the different axes loosens the cohesion of the particles. After rainfall in winter the advent of frost causes the water which may have found its way into cracks and crevices to expand with such force as to disintegrate particles, and to loosen large masses of rock, which are thereby made more available for other disintegrating influences. The waters of seas, lakes, and river, likewise, are ever gradually disintegrating and crumbling down the rocks over which they pass, and bearing away the detritus for the formation of alluvial soil elsewhere.

The Chemical Forces make themselves evident in the decomposition of the constituent parts of the rocks through the action

* Page's "*Introductory Text-book of Geology*," 1871, p. 16.

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of water, by oxidation or deoxidation, and in the changes effected by means of carbonic acid.

Water is found in the solid state as water of crystallisation in many salts; when heated the water is driven off, and the salt crumbles into powder. All rocks are porous, although in some cases only to a very slight extent, and are therefore penetrable by water; all, too, are soluble and liable to transformation into other chemical combinations. Absolutely pure water is never found in the earth's crust, that met with being generally impregnated with some other substance like carbonic acid, which assists it in the task of producing modifications of existing combinations. Through the addition of water anhydrite ($CaSO_4$), becomes gypsum ($CaSO_4 + 2H_2O$), and is then soluble in water in the proportion of about 1 in 400, when it occasions *permanent hardness*, which cannot be removed by boiling; calcium carbonate ($CaCO_3$), contained in limestone and chalk, is only soluble in water to the extent of about 1 in 10,000, but readily dissolves in water containing carbonic acid, and then gives rise to the condition known as *temporary hardness*, which may be removed by boiling, when the carbonic acid escapes, and a crust of calcium carbonate is deposited as *fur* in the boiler or kettle.

Most of the elements are found in rocks in a fully oxidised condition, and are therefore incapable of taking up more oxygen. Ferrous oxide (FeO) and ferrous disulphide or iron pyrites (FeS_2) occur, however, in hornblende, augite, chlorite, and many other minerals, and their transformation into oxides is an essential step towards the process of decomposition. Water impregnated with carbonic acid has a powerful action in dissolving silicates which contain alkaline earths and ferrous oxide; carbonate of lime ($CaCO_3$), and ferrous carbonate ($FeCO_3$) in particular are easily soluble, whilst magnesium carbonate ($MgCO_3$) is very difficult of solution.

The products of the combinations vary according to the original composition of the minerals; but in all cases the water taken up is held in chemical combination, forming substances that contain water, and the products of decomposition are divisible into those capable of being carried away elsewhere in solution, and those not removable in such manner. Thus, on the disintegration and decomposition of the various kinds of feldspar ($AlKSi_3O_8$) by the action of the air and of water, a soluble alkali is washed away, and an aluminium silicate is left behind in the form of *clay*. The products of decomposition are mostly alkalies in combination with silica and carbonic acid, and

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carbonates of lime, magnesia, and ferrous oxide, whilst in nearly every kind of soil is found a greater or less admixture of soluble sulphate of lime. These solutions and soluble salts are capable of acting mutually on each other, so that many different combinations are formed.

The most easily decomposable rocks are those of complicated structure, or which contain minerals liable to be subjected to chemical processes. Thus quartz rock and silicious slate decompose very slowly, whilst rocks rich in feldspars and combinations of iron decompose rapidly; pure lime is difficult of decomposition, but with increase of alumina and iron in its structure this difficulty diminishes. Conglomerates and sandstones disintegrate in proportion to the amount of cohesive or cementing matter contained by them, to the capacity of this for being softened by moisture, transformed, and held in solution, and to the extent to which they alternate with soft bands or layers of clay-slate, marl, &c. Coarse-grained rocks and slate-formations liable to crack and fissure decompose more rapidly than fine-grained or massive rocks, as they afford greater facilities for the penetration of the atmosphere and of meteoric water, and a favourable foothold for lichens, mosses, and other vegetation.

The Organic Agencies.—Without considering infusorial organisms, coral zoophytes, and the operations of earth-worms, which, particularly in tropical countries, play rather an important part, it is essentially the vegetable world that exerts the greatest influence on the formation of soils, both during the period of life of the organisms, and whilst after death they undergo the natural processes of decomposition and decay.

When soils were first formed, only the lowlier forms of vegetable life could maintain an existence. When the period of vitality of these individual organisms was at an end, a process of decomposition set in under the atmospheric agency. The products of the decomposition, in admixture with the existing soil, assisted in the work of decomposing the rocks so as to form more soil, and gradually the evolution of the higher forms of vegetation, and of the various forest trees, took place along with the formation of soil, and consequent on various favourable conditions. This process of decomposition, dependent upon oxygen, moisture, and a certain minimum degree of heat (52° Fahr.), is known as the formation of *humus, leaf-mould, or vegetable mould,* which has been defined by Liebig as "*all organic matter undergoing the process of decomposition.*" When formation of humus or mould from fallen leaves, twigs, branches, undergrowth, and dead timber takes place under full exposure

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to the atmosphere, water, carbonic acid, and ammonia are produced, and carbon is left behind as mould; $(N + C_{36}H_{22}O_{22}) + O$ of the atmosphere, becomes either $H_2O + CO_2 + NH_3$, or else $H_2O + CO_2 + N$, leaving in either case C_{25} behind as an uncombined remnant.

The normal formation of humus or mould takes place most favourably under ordinary density of leaf-canopy overhead, and when the soil-covering consists of dead leaves, needles, scales, bracts, fallen twigs, &c., together with weeds which do not form woody tissue.

In addition to the better *woodland humus* or *forest mould* the following inferior qualities may also be distinguished* :—

Coaly humus, when owing to interruption of the normal process of decomposition it forms a distinct blackish layer above the soil.

Mountain humus or heather mould, when it consists chiefly of heather, heath, whortleberry, along with similar wild growths.

Moorland or acid humus, also formed for the most part of weeds, but when excess of soil-moisture interferes with the normal circulation of air necessary for the process of favourable gradual decomposition.

Dusty humus or dry mould, which crumbles into powder when dried up, and has small hygroscopic power afterwards.

When the decomposition takes place only under partial exposure to the atmosphere, humic acid ($C_{40}H_{12}O_{12}$), other similar acids, and marsh gas (CH_4) are produced, whilst fungoid growths also aid the work of decomposition, attacking first of all albuminoid substances. The humic acid and other similar acids (ulmic, geïn, &c.) produced have a very strong affinity for ammonia, which itself is essential to the nourishment of forest growth, as plants have only a limited power of assimilating the free nitrogen of the air. The older agricultural chemists, headed by Boussingault, asserted that plants could not directly utilise the free nitrogen contained in the air. But of recent years it has been often proved by Hellriegel, Frank, Wilfarth, Ville, and others that this can and does take place, more particularly in the case of the *Leguminosæ, e.g.* the Acacia; so long, however, as a supply of nitrogenous food is available in the soil, this capacity, for which the symbiotic aid of a *bacillus* is requisite, is not called into play.† The recent researches of Munro, Lawes, and Gilbert in England,‡ of Frank, Mayer, and Hellriegel in Germany, and of Kostycheff in Russia, following on former discoveries of Schlösing and Müntz, prove the important influences exerted by

* Weise, "*Leitfaden für den Waldbau*," 1888, page 111.

† But see "*Nineteenth Century*," August 1893, p. 260.

‡ *Vide* two articles, "*The Nitrifying Ferments of the Soil*" and "*The Sources of the Nitrogen of our Leguminous Crops*," in the Journal of the Royal Agricultural Society of England for first quarter of 1892.

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minute living organisms (microbes) in the process of nitrification or conversion of nitrogen into a nitrate (usually nitrate of lime) before it can enter the tissue of plants. Winogradsky made the important discovery that the nitrifying ferments obtain the carbon needed for their nutrition from the carbonic acid of the carbonate of lime or carbonate of magnesia contained in the soil, thus revealing a hitherto unsuspected attribute of living organisms, the power of directly utilising the carbon of mineral carbonates for the purposes of growth.

Humus condenses gases and atmospheric moisture. It is also warm, partly on account of its retaining well the warmth received from the sunshine and air, and partly because of the development of heat occasioned by the chemical process of decomposition. Hence, whilst mechanically making stiff soils less tenacious and loose soils more binding, it at the same time warms cold soils slightly, and makes sandy land less easily heated and more retentive of moisture.

As the existing supplies of humus are gradually though constantly being used up, fresh supplies become necessary. These are obtained from the annual fall of leaves, twigs, &c., and the growth of mosses and weeds; hence the continuous removal of humus or of dead foliage from woodland tracts must ultimately lead to diminution in the productive capacity of the soil.

Apart from the importance of carbonic acid as one of the chief nutriments of woodland vegetation, it is also of incalculable value in the decomposition of the soil and the preparation of mineral substances for absorption by plants.

The humic acid assists in the work of nutrition by forming solutions of the alkalies (potassium and sodium), which are active in decomposing the mineral constituents of the soil. Senft found that the salt formed by humic acid and ammonia dissolved the silicates of the alkalies and of magnesia, the sulphates of lime and of strontium, and the phosphates of lime and iron.

The higher vegetable organisms also mechanically exert enormous influence on the formation of soil by the disintegrating and cleaving action of their root-systems, which penetrate into the masses of stone and rock forming the base of the soil and subsoil, and later on increase the already produced effects by the decomposition of the woody-fibrous matter of which they are composed.

3. *Classification of Soils as to their Origin and Mineral Composition.*—Soil may be found either remaining on the spot where it was originally formed, as on the slopes of hills and on undulating or high ground protected against having the soil

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washed away, or it may have been translated by aqueous agency from where it was formed by decomposition of the parent rock to other and far distant localities. Such translations are daily taking place around us; streams deepen their courses, and rivers their channels; waves and tides weather and wear away the cliffs on which they beat; frosts crumble down the rocky surfaces, and rains wash away the loosened particles; estuaries and lakes are filled with deposits of rubble, breccia, pebbles, sand, loam, and clay, and these sub-aqueous *alluvial deposits* are in course of time made available for sustaining the higher forms of organic life by the natural processes of upheaval and submergence, due to agencies in operation below the crust of the earth.

When the pleistocene group of the tertiary system was being formed, large accumulations of sands, clays, marls, gravels, and boulder-stones embedded in clay without regard to gravity or any assignable laws, were deposited—here in masses, there scattered over wide tracts of land, seldom or never appearing in regular strata—to which the name of *diluvium* or *diluvial drift* was given. Their accumulation was due to the deposit of débris contained in icebergs when the climate became milder, and their appearance as soil took place when the land gradually rose to its present level. These diluvial deposits are found to comprise fragments of all the older rocks, from granite and gneiss up to sandstones, clays, and chalk.

Any attempt at classification of soils according to the nature of the rocks from which they have been formed is of little value. For, *firstly*, one and the same rock does not always yield similar soil (*e.g.*, granite containing much feldspar will decompose quite differently from granite consisting mainly of quartz); *secondly*, the soil from any particular rock depends on the stage of decomposition arrived at (*e.g.*, kaolin has quite different properties from feldspar in the preliminary stages of transformation); and *thirdly*, the products of decomposition are not always retained together (*e.g.*, clay is washed away more easily than sand).

The only practically useful classification is that according to the principal constituents contained in the soil. For the practical purposes of forestry there is no better classification than that of Grebe into:—

Sandy soils, containing 75 per cent. or more of disintegrated sand. They occur as sand-drifts, or are the product of the decomposition of sandstones.

Sand consists of about 90 per cent. of sand, and not more than 10 per cent. of clay and other constituents.

Loamy sand consists of about 75–85 per cent. of sand, and 15–25 per cent. of clay and other constituents.

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LOAMY SOILS, always more or less coloured with iron, containing 60–70 per cent. of the finest sand and silicious dust, the rest being made up chiefly of clay with less than 5 per cent. of lime and an almost constant quantity (5 per cent.) of hydrated ferric oxide.

Loam consists of, roughly, 60 per cent. of sand and 40 per cent. of clay.

Sandy loam consists of, roughly, 70 per cent. of sand and 30 per cent. of clay.

CLAYEY SOILS, containing 50 per cent. and more of clay. They mostly result from the decomposition of rocks rich in feldspars, augite, and hornblende, of sandstones and conglomerates cemented with clayey cohesive substance, and of the clayey layers and bands occurring in sandstones and lime formations.

Clay consists of about 60–70 per cent. of clay, the rest being made up chiefly of sand and other constituents.

Loamy clay consists of about 50 per cent. of clay and 50 per cent. of sand.

LIMY SOILS, containing not less than 10 per cent. of carbonate of lime. They are the product not only of the limestones proper, but also of other rocks, especially such as contain the feldspar Labrador. Not infrequently the product of the decomposition of limestone rocks yields a loamy rather than a limy soil.

Lime consists of at least 50 per cent. of carbonate of lime, the rest being made up chiefly of clay.

Clayey lime consists of about 40 per cent. of lime and 60 per cent. of clay.

Loamy lime consists of about 30 per cent. of lime and 70 per cent. of loam. It is often rich in carbonate of magnesia, and is then known as *dolomitic lime* or *dolomite*.

Marl consists of 10–20 per cent. of carbonate of lime with 80–90 per cent. of clayey and sandy constituents.

Sandy soils are recognisable by their coarse gritty feeling when moistened and rubbed between finger and thumb. According to the admixture along with the sand it is classed as loamy, marly, ferruginous, or humose. Quartzy sand becomes easily heated and cooled, offers little nutriment to plants, and is not retentive of nutrients, of moisture in particular; it therefore belongs to the poorer classes of soil, on which trees require a large growing-space to obtain the necessary supplies of food, on which also they soon become interrupted in canopy, are deficient in annual increment, produce seed seldom, and are deficient in reproductive capacity from the stool as well as in natural regeneration from seed. By becoming easily warmed in spring they stimulate to early germination of seed, movement of sap, and flushing of leaves, thereby exposing the young shoots to danger from frost, which is increased by rapid evaporation of moisture and radiation of heat from sandy soil. The more earthy the composition of sandy soils, the better their quality. The treatment to be accorded to any particular species of forest tree on sandy soils depends on its general growth and development; should this be good, natural reproduction under parent standards is safe and easy, but if it be indifferent, the latter mode of regeneration should never be attempted.

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When sandy soil is being brought under forest for the first time, the crop should consist principally of Scots pine until from its growth one has had a fair opportunity of judging of the true sylvicultural value of the land and of estimating for what mixed crops it is best adapted.

Clayey soil sticks when placed to the tongue, and when breathed on emits an odour of ammonia; when rubbed between finger and thumb it feels fatty, and when rubbed with the finger-nail it takes a sort of rough polish. The clay is mostly tinged with iron, and varies in colour from grey, through yellow, up to brownish-red. The characteristics of a clay soil are its tenacity, its weak hygroscopic power, and its impermeability and retention of moisture when saturated; it is cold, not easily heated, and has a tendency to become waterlogged. These characteristics are modified by any considerable admixture of sand, iron, lime, or marl, in which case the soils are termed sandy, ferruginous, limy, or marly clays. As the movement of the soil-moisture is slow, nutrients are not apt to be washed out of the layer permeable by the roots of trees, so that clayey soils offer large supplies of mineral food within small space, in consequence of which the requisite individual growing-space is smaller, and the density of the canopy greater, throughout all stages of development of the crop than on sandy soils. Porosity and permeability of subsoil prevent stagnation of the soil-moisture and tendency to the formation of marshes. As a bad conductor of heat, a clayey soil does not stimulate to early germination of seed or the opening of buds in early spring, and though the growth of crops is at first somewhat slow, this improves considerably later on. As the density of the canopy is usually great, and the dead foliage only decomposes slowly on the cold soil with little sunlight playing over the surface, a heavy fall of leaves litters the ground, so that for natural reproduction a good deal of soil-preparation is necessary. Preparatory clearings for this purpose are usually followed by rich production of seed, and the whole operation of regeneration is made easy by the greater amount of shade which the seedlings are here enabled to bear. In copse and coppice, also, the reproductive power is in general greater than on sand.

Limy soil effervesces when nitric acid is dropped on it. Marls and true limes belong to this category, the difference being that in the former the limy constituent is equally admixed throughout each particle of the soil, whilst this is not the case in the latter variety. According as the other components consist of clay, loam, sand, or stones, soils are classed as clayey,

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loamy, sandy, or stony marls or limes. Such soils are apt to be wanting in depth, but under judicious treatment they very frequently show good growth of timber, as they have a favourable degree of consistency enabling moisture and warmth to be equably distributed throughout, even on steep hillsides, so that the root-system can easily attain its normal development and be assured a plentiful supply of nutrients. When, however, through injudicious treatment the soil has been exposed to insolation, and allowed to become deteriorated, the retention of soil-moisture diminishes; evaporation and the downward flow of water are both greater; the soil soon sets closer; and it becomes shallower, drier, and hotter. These changes take place so rapidly that measures can hardly be taken sylviculturally to remedy the mistakes made. The rewooding of deteriorated limy soil is usually a work requiring great time, patience, and outlay. In many cases excellent results have been obtained by sowing lucern (*Medicago sativa*), and at the same time planting out black pine or sowing beech-nuts, the lucern being left to decompose and improve the soil, instead of being harvested.

On limy soils the retention of an undisturbed soil-covering of dead foliage and humus is a matter of vital importance for their productive capacity; hence, in general, natural reproduction under the parent standards ought to have a preference. As the humus is rapidly formed, soil-preparation is seldom requisite; seed production is usually good, the germinative power high, and the capacity of the seedlings for bearing shade above the average. The greater the proportion of stones or sand in limy soils, the more caution must be exercised in the reproductive measures, as well as in the tending of the woods generally, in the thinnings out, &c. The general energy of growth on well-protected limy soil is also evidenced by strong reproductive capacity in coppice through stool-shoots and stoles, and by the long vitality of the stools.

Loamy soil has more in common with clay than with sand, but does not feel fatty when rubbed between finger and thumb, and takes only a very imperfect polish when rubbed with the finger-nail. Loamy soils are generally characterised by their mildness. They approach more to clays or sands according to the degree of the sandy admixture; but any admixture of lime, either unequally distributed and easily separable as in the case of limy loams, or equally distributed and thoroughly mixed as in the case of marly loams, lends it rather the characteristics of a limy soil. The nature of the subsoil is of special importance

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in regard to the distribution of moisture throughout heavy soils, though in general they are favourable for sylvicultural operations; the choice of species of trees is usually guided rather by the other factors relating to situation than by those having reference to the mineral composition of the soil. At high elevations the spruce should in general form the ruling species in mixed forests on loamy soils, whilst in lower-lying localities the oak is one of the species which thrives best.

Natural reproduction is easy when once a good seed-year has come round. But the production of a good harvest of seed cannot always be reckoned on, so that whenever there is any danger of the soil becoming slightly deteriorated by insolation during preparatory fellings, or whilst awaiting the advent of a favourable seed-year, artificial assistance, either by means of sowing or planting, is advisable before the deterioration makes itself evident in any decided degree.

In addition to these principal classes of soil, a minor recognition is also made of *humose* and *ferruginous* soils.

Humose soils are such as contain 20 per cent. or more of humus or vegetable mould. Although plainly coloured with mineral particles, they are not infrequently found of such depth that the true mineral soil below cannot be reached by the roots of trees. This is the case in marshes, moors, and peat-bogs formed by the decomposition of grasses, heather, heath, whortleberries, mosses, &c., under partial access of the atmosphere, low temperature, excess of moisture, and impermeable subsoil; usually these are found on sandy soil, resting on clay. The fertile silt deposits left behind after inundations of streams and rivers are often to a very great extent humose in their character.

Humus not only adds depth to the soil, but from its strongly hygroscopic quality condenses atmospheric moisture, whilst as a bad conductor of warmth it acts as a regulator and protects the soil from parting too rapidly with its soil-moisture and becoming parched and dried up; by developing carbonic acid it also assists in the decomposition of the mineral constituents in the soil. It modifies all extremes of physical properties, and though not an absolute necessity for forest growth, yet exerts a powerful influence on it, and is of inestimable value in stimulating the productive capacity of the soil, no matter of what origin the latter be. Humose soils take their main character from their mineral composition; but the beneficial influence they exert on tree-growth is permanent so long as the

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natural reproduction of humus is not interfered with by interruption of the canopy, &c., since high forest annually gives larger supplies of dead foliage for the formation of vegetable mould than it consumes.

Natural reproduction is often interfered with on humose soils through rank growth of grass and weeds; and even the thriving and the very existence of young plantations of seedlings or small transplants are often endangered from this cause. Where the admixture of humus in the soil forms a high percentage, the tending of woods often requires great care; with an excess of soil-moisture such soils are apt to swell up and form mud, whilst in seasons of drought they run the opposite risk of shrinking and losing consistence. Heather-mould and peat soils do not change so much in appearance, but when they begin to dry up they become so heated that the woodland growth is considerably affected.

Ferruginous soil contains at least 10 to 15 per cent. of ferric oxide or hydrated ferric oxide, and is characterised by its brown-red colour. The general character of sandy soil can become affected by even such small admixtures of ferric oxide as two to five per cent., whilst loamy and clayey soils can often contain much larger percentages without their characteristics becoming perceptibly altered. Thus *moorpan* may contain only about two per cent. of ferric oxide, whilst *iron-band* or *limonite* contains 60 to 70 per cent.; yet both equally hinder the growth of forest trees, except they are broken through so that the subsoil can be reached by the roots, and the circulation of water can take place properly throughout the soil.

If the fertility of soils depended only, or even for the most part, on the mineral richness of the parent rocks, a classification of soils according to their relative strength would be simple; but it is unsafe and incorrect to say more than that clayey soils are usually slow in action in decomposing vegetable matter and yielding food-supplies to tree-growth, that limy soils form humus quickly and stimulate forest growth, and that sandy and loamy soils in general occupy an intermediate position between these two, except when the sand is wanting in a favourable degree of moisture.

4. *The Physical Properties of Soils.*—To these, in a far greater degree than to the mineral composition of any soil, is due its capacity to sustain timber crops, and to yield to them in due proportion the various forms of nutriment requisite for their growth, development, and reproduction. All the

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physical properties act and react on each other in determining the quality of any soil for sylvicultural purposes.

(*a.*) *Cohesiveness or Tenacity* is the resistance offered by a soil to instruments used in separating its particles, or to force used in disintegrating them. This property is not alone of importance in relation to air, moisture, and warmth, but also indicates the resistance to be overcome by root-systems in penetrating into and ramifying throughout the soil.

Clay soils have the greatest cohesiveness, sand the least; lime approaches more to the clay, whilst loam resembles rather the sand. An admixture of humus tends to obliterate the differences, making clays and limes less tenacious, and loams and sands more binding. The tendency of soils to expand with moisture, and shrink on parting with it again, is practically proportional to its tenacity. Soils may be classified in this respect as—

Heavy, stiff, or tenacious soils, which fissure and crack deeply when dried up. Clays and clayey loams, limes, and marls belong to this class.

Mild soils, exhibiting superficial cracks when suddenly dried up, but which when nearly dry have the power of retaining the form of clods. They are usually composed of favourable admixtures of clay, sand, and lime, as in loams, sandy loams, and loamy limes.

Light soils, capable of forming clods when moist, but when dry showing a strong tendency to disintegrate, as in the case of loamy sands and sandy marls.

Loose soils, which even when moist have little tendency to form clods. To this class belong the poorer sandy soils.

Shifting soil, liable in a dry condition to be carried away by the wind; sand-drifts and dunes.

In a light soil not deficient in moisture, humus, and mineral nutrients, a maximum of rootlets can be developed, and through these the maximum of timber. Hence one finds the greatest increase in cubic contents, and in particular the greatest increase in height, on alluvial deposits consisting of finely pulverised particles. Looseness of soil, however, if accompanied by deficiency of moisture, is detrimental to the development of plants, especially at the earlier stages of their growth, as such soils part too readily with the water received in the form of rain.

(*b.*) *Relation to Moisture.*—The degree of moisture contained in any soil is one of the principal factors in determining its capacity for sustaining forest growth. No plant can take root, develop, and thrive without a due supply of moisture; it is essential to germination; it is the means by which supplies of food are made available for plant life; it is the source whence are obtained the enormous quantities of water transpired through

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the foliage; it regulates the soil-temperature; it acts beneficially by making heavy soils somewhat milder, and loose soils somewhat more tenacious. Excess of moisture, however, hinders the normal process of the chemical activity of the soil, tends to clog it, by interfering with the process of formation of humus, with injurious acids and acid solutions, and leads to the formation of marshes and moors; it kills seed, and robs it of a certain amount of germinative power; by supplying the young plant with superfluous nourishment and moisture it leads to disease, especially in the root and stem; being a bad conductor of heat, and not easily warmed, it interferes with the natural activity of the soil, and increases danger from frost.

Capacity for absorbing and retaining meteoric precipitations, and for absorbing hygroscopically and condensing on its surface the aqueous vapour contained in the atmosphere, are dependent on the fineness of the soil-particles; whilst permeability or power of diffusing moisture throughout the soil is proportional to the size of the particles of which the soil is made up. Experiments by Schübler showed that soils may be classed as under:—

Order.	Absorptive Power as to		Power of retaining Moisture.	Power of diffusing Moisture (Permeability).
	Rain-water.	Aqueous Vapour.		
1	Lime	Clay	Clay	Sand
2	Clay	Lime	Lime	Loam
3	Loam	Loam	Loam	Lime
4	Sand	Sand	Sand	Clay

The admixture of humus generally found in soils tends here again to modify all hard and fast differences exhibited by the various classes of soil.

According to the average amount of moisture contained in soils during the period when tree-growth is most active, soils are classified by Heyer and Grebe as under (a classification now adopted at all German experimental stations):—

Wet, when, on a clod being lifted up, water flows out without pressure being applied.

Moist, when water falls in drops from a clod on pressure being applied.

Fresh, when, on pressure being applied to a handful of soil, only traces of moisture are left on the hand.

Dry, when on being rubbed it does not resolve into dust. Such soils lose their moisture within a few days after rainfall, and their colour is not much deepened by the moisture retained.

Arid, when on being rubbed it resolves into dust that is carried away by the wind. Traces of rainfall rapidly disappear from such soil, and the slight quantity of moisture it is able to retain does not affect its colour.

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The majority of our forest trees—oak, beech, maple, spruce, Scots pine, larch, silver fir—thrive best on a fresh soil; poplars, willows, elm, ash, and hornbeam prefer a moist, and the alder a wet soil; stagnating water is beneficial to no kind of timber. A dry soil is not demanded by any forest tree, but birch, aspen, and Scots pine are able to thrive with less soil-moisture than other species.

Comparative data are not yet available to show the absolute quantities of soil-moisture necessary for the various species of forest trees to enable them to carry on throughout the annual period of vegetation the work of evaporation and transpiration through the foliage. Experience, however, shows that the demands vary as follows:—

Requiring moist soil: Alder, willow, ash.
Requiring fresh to moist soil: Spruce, oak, beech, elm, maple, sycamore, hornbeam, silver fir, larch, chesnut, white alder.
Preferring dry soil: Scots and black pines, mountain ash, aspen.

The sylvicultural qualities of a soil are frequently, to a very great extent, indicated by the nature of the forest weeds that grow upon it. Thus we have characteristic plants as under:—

1. *On wet or boggy soil:*—Bog moss (*Sphagnum*), hair moss (*Polytrichum*), cranberry (*Vaccinium oxycoccos*), bog bilberry (*Vaccinium uliginosum*), marsh cistus or marsh rosemary (*Ledum palustre*), cotton grass (*Eriophorum*), sedges (*Carex*), bulrushes (*Scirpus*), rushes (*Juncus*), the last three in many different species.

2. *On fresh fertile soil, or soil rich in humus:*—Raspberry (*Rubus idæus*), bramble (*Rubus fruticosus*), red foxglove (*Digitalis purpurea*), willow herb (*Epilobium angustifolium*), deadly nightshade (*Atropa belladonna*), balsam (*Impatiens noli-me-tangere*), stinging nettle (*Urtica dioica*), hemp nettle (*Galeopsis tetrahit*), vetches (*Vicia*), and species of clover (*Trifolium*), as well as ferns and broad-leaved grasses of different sorts.

3. *On drier and more sandy soils:*—Heather or ling (*Calluna vulgaris*), heath or bell-heather (*Erica tetralix*), bilberry or whortleberry (*Vaccinium myrtillus*), red whortleberry or cowberry (*Vaccinium vitis idea*), whin, gorse, or furze (*Ulex*), broom (*Spartium scoparium*), greenweed (*Genista*), groundsel and ragwort (*Senecio*), mullein (*Verbascum*), hawkweed (*Hieracium*), spurge (*Euphorbium*),—the last-named genera occurring in various species,—and the narrow-leaved meadow grasses.

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The shrubs which occur most frequently on hills and valleys, especially when the soil is fresh, are: Black alder or alder buckthorn (*Rhamnus frangula*), blackthorn or sloe (*Prunus spinosa*), hawthorn (*Cratægus oxyacantha*), spindlewood (*Euonymus europæus*), dogwood (*Cornus sanguinea*), barberry (*Berberis vulgaris*), holly (*Ilex aquifolium*), honeysuckle (*Lonicera periclymenum*), elderberry (*Sambucus*); on drier soil, juniper (*Juniperus vulgaris*), and on sandy soil, buckthorn (*Hippophae rhamnoides*).

(*c.*) *Relation to warmth* is exhibited in the capacity any soil shows for increasing and diminishing its temperature in correspondence with changes in the atmospheric temperature. It has little to do with the specific warmth of the different kinds of soil, but is determinable rather by their colour, and especially by the quantity of moisture contained in them.

Soils, like clay, which retain moisture are cold and inactive, whilst sandy and gravelly soils become easily heated and stimulated, but are liable to the danger of radiating their heat too rapidly, and becoming easily cooled below the freezing point.

Differences in temperature from day to day disappear in our latitudes at about 20 inches below the surface, those from week to week at 40 inches, and those from month to month at about 6½ feet.

(*d.*) *Depth.*—At the surface of the earth the process of decomposition has gone on further than at lower depths. The finest soil is found near the top; and the deeper one goes below the surface, the larger become the stones and breccia undergoing decomposition, till a layer is touched that is practically beyond the reach of decomposing factors, or is of quite a different nature from the soil.

In proportion as a soil is available for the penetration of the root-system and the atmospheric influences, it is termed deep or shallow. The layer of mineral substance available for the roots, or so much of it as is penetrated by the roots, is called the *soil*, whilst whatever is below that is termed the *subsoil*.

Depth of soil is of especial importance in the case of trees like the oak, which, as a rule, do not develop any considerable length of bole if the growth of their tap-root be interfered with. Even trees with shallow root-systems, *e.g.*, beech, hornbeam, birch, aspen, and spruce, thrive better on deep than on shallow soils, as the former generally retain the soil-moisture longer and give it off more gradually, whilst the latter usually suffer from

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drought or excess of moisture. The disadvantages and drawbacks of shallow soil are more pronounced when the subsoil consists of horizontal layers of plastic clay, of uncleft and impermeable strata, or of ferruginous deposits like moorpan.

Under the instructions for the German experimental stations, forest soils are classified with reference to their depth as follows:—

Very shallow: Up to 6 inches only.
Shallow: From 6 inches to 1 foot.
Medium: From 1 to 2 feet.
Deep: From 2 to 4 feet.
Very deep: Over 4 feet, beyond which depth tree roots seldom penetrate.

Among forest trees the oak makes greatest demands on depth of soil; spruce, birch, and mountain ash make least.

The following table expresses, only, however, in general terms, the depth of soil necessary for the various species of forest trees to thrive normally:—

Up to 1 *foot:* Spruce, aspen, mountain ash, birch, mountain pine.
1 *to* 2 *feet:* Beech, hornbeam, alder, black or Austrian pine, Weymouth pine.
2 *to* 3 *feet:* Scots pine, silver fir, Douglas fir, elm, maple and sycamore, ash, lime, sweet chesnut.
3 *to* 4 *feet:* Oak, larch.

When it is considered that one and the same rock has not always the same composition, that the products of the decomposition of any particular kind of rock often differ in their composition from that of the parent rock and may be endowed with different physical properties, and that these latter are not dependent on the parent rock, the conclusion must be arrived at that no hard and fast deductions can safely be drawn concerning soils from consideration of their geological origin only. Depth, nature of subsoil, relation to moisture, and admixture of humus, are often of equal and even much greater importance as regards the growth of timber crops.

II.—Situation in Relation to Forest Growth.

1. *Climate.*—The various kinds of forest trees are unable to thrive, or even to grow at all, everywhere over the surface of the earth. Their capacity for growth and reproduction are limited by certain factors or conditions relating to the distribution of heat and moisture, combined under the expression *climate.* Some require for their development a greater amount of heat and sunshine than others, and thrive where the latter cannot exist; some can not only endure, but prefer, a considerable degree of cold during the non-active season of the year. Some,

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with strong power of transpiration through the foliage, require a damp climate; others prefer a dry condition of the air.

(*a.*) *Warmth.*—The climate of any locality is determined by its general geographical position, with special reference to its latitude from the equator, modified, however, by its position with reference to seas, continents, and mountain ranges, to its elevation above the sea-level, and its exposure to winds.

As regards mean annual temperature, Britain is, in consequence of its insular position and of the genial equating influence of that branch of the Gulf Stream which reaches its shores, situated on the same isothermic lines as many parts of Southern Europe. As to warmth in summer it is only on the same isotheric (July) lines as Northern Europe (Baltic), whilst as to average temperature in winter it occupies a position on the same isochimenic (January) lines as Northern Italy, Southern Austria, and Turkey.

Temperature falls with elevation above the sea-level and distance from the equator. Experiments at Würzburg showed that the ascent necessary for the reduction of temperature by 1° Fahr. was—

During the month of		During the month of July.	
January - -	327 feet.		
April - - -	312 „	At 10 a.m.	237 feet.
June - -	210 „	„ 2 p.m.	207 „
September - -	243 „	„ 4 „	311 „
December - - -	363 „	„ 10 „	233 „
Average - -	291 feet.	Average -	247 feet.

According to Angot, tree vegetation is later by 14 days for every 333 feet in vertical ascent above the sea-level.

No definite data can be given for the reduction of temperature with progression northwards, as the configuration of the soil exerts such powerful influences in different localities. Low-lying tracts, shut in by hills, are much more liable to frosts than those similarly situated as to latitude and sea-level, but freely open to the action of air-currents. No portion of Britain ascends to the line of perpetual snow.

Heat and light, a form of heat, are essential to the growth and development of forest vegetation, as it is only under their influence that the chlorophyll in the foliage is enabled to

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decompose the carbonic acid and water in the atmosphere, for the purpose of carrying on the work of assimilation and nourishment. When there is an excess of light, assimilation may be interfered with in the case of lowlier plants; but so far as forest trees are concerned, the more light and air they are allowed to enjoy, the more luxuriantly do they grow and thrive.

In the case of the evergreen conifers the limitation of growth towards the north or on lofty mountainous tracts is often not so much due to the actual degree of cold to which they are exposed, but is principally caused through dry winds on sunny days in winter stimulating transpiration through the leaves at a time when the roots can draw no fresh supplies of moisture from the frost-bound soil. Owing to the loss of moisture contained in the tree the foliage becomes yellow and sickly, the growth impaired and diseased, the leaves fall off, and finally the death of the tree ensues. This phenomenon is most distinctly noticeable after long dry winters with comparatively frequent sunshine.*

Experiments are being made to establish the absolute amount of warmth requisite at different localities in order to ensure the normal development of each of the principal species of forest trees, but no definite conclusions have yet been come to. Gayer† estimates the requirements as to warmth according to the following scale:—

Requiring most: Elm, sweet chesnut, oak (*Q. pedunculata*), black, Austrian, or Corsican pine.
Then: Silver fir, beech, Weymouth pine, oak (*Q. sessiliflora*), Scots pine.
Then: Birch, maple and sycamore, ash, alder, spruce.
Requiring least: Cembran pine, larch, mountain pine.

The demands on warmth naturally to a certain extent limit the different species of trees to definite zones of elevation, which, however, are very much modified by quality of soil, exposure, and local climatic considerations.

Whilst an excess of light, the minor form of warmth, may paralyse the action of chlorophyll in lowly plants, deprivation of the due measure under which assimilation proceeds most favourably exerts an injurious influence on tree-growth. But so far as temperate climates are concerned, forest trees thrive best when they enjoy full exposure to brilliant sunshine.‡ The relative minima demands of each species on light, sunshine, warmth, and air combined, are easily recognisable through inability of the crop to remain long in close canopy, and through

* R. Hartig, "*Lehrbuch der Baumkrankheiten*," 2nd edition, 1889, pp. 104, 261.
† "*Der Waldbau*," 3rd edition, p. 20.
‡ See essay on "*The Enhancement of Increment in Tree-Forest*," &c., pp. 8 and 9.

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the quick dying off of overshadowed twigs and branches. But such demands vary so much with soil and situation, that we know as little about the absolute amount of light requisite for any species as we do concerning the absolute amount of warmth. From practical experience and observations made on woodland crops growing on soils of only average quality, where their true characteristics are most apparent, British forest trees and acclimatised exotics may be ranged thus :—

Light-demanding : Larch, Scots pine ; birch, aspen, willow.
Less-exacting : Mountain, Austrian or Corsican, and Weymouth pines ; oak, ash, chesnut, elm, alder, maple, sycamore, lime.
Shade-bearing : Spruce, Douglas fir, Nordmann's fir, silver fir ; hornbeam, beech.

Whilst woody plants suffer little from frost during winter, late frosts in spring and early frosts in autumn often occasion much damage to the soft shoots. Danger from frost is greater on plains than in hilly tracts, greater on S. and S.E. exposures than on N. and W., greater in valleys and coombs than on ridges and shoulders of hills, greater in localities protected from the wind than in those where currents of air have free play, greater in a dry state of the air than in a moist, greater on fresh soil than on dry, and greater on loose sandy soil than on a stiffer loam. Gayer classifies the forest trees with reference to their liability to suffer from frost as follows :—

Liable : Ash, acacia, sweet chesnut, beech.
Less liable : Oak, silver fir, maple, sycamore, spruce, alder.
Hardy : Lime, hornbeam, elm, birch, larch, aspen, Austrian and Scots pine.

The liability to suffer depends, however, less on the species than on the stage of growth to which the young shoots have advanced. It is greater in weakly than in healthy and vigorous plants ; greater too in plants suddenly exposed after having long had the shelter of standards than in those that have been gradually accustomed to the loss of shelter.

(*b.*) *Atmospheric Moisture* is determinable by nearly the same factors as warmth, for it is dependent on the atmospheric temperature. The warmer the air, the greater its capacity for retaining aqueous vapour in suspension ; hence all conditions influencing temperature also affect the condition of the atmospheric moisture.

The absolute humidity of the air decreases with increase of latitude, but no rule is traceable in this respect as to relative humidity, for different localities vary as regards the quantity of water available for evaporation.

With elevation above the sea-level the absolute humidity decreases ; the relative humidity, however, decreases only in

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clear, fine weather, but increases at all other times, so that on the average it may be said to increase.

The humidity of the air is dependent on winds. Warm winds blowing across seas or large lakes have a high degree of absolute humidity; in winds from localities without much water increased temperature necessitates decreased relative humidity. In Britain generally the N.W., W., and S.W. winds have the greatest relative humidity; those from the E. are comparatively dry. On the continent of Europe the relative humidity of the air decreases from W. to E.

When atmospheric temperature becomes reduced, aqueous precipitations take place in the form of dew, rain, hail, or snow; hence at high elevations these phenomena will be of more frequent occurrence than in lower localities, whilst at the same time atmospheric disturbances generally are also of greater frequency and violence.

If aqueous precipitations did not take place largely forest growth would be impossible, as enormous quantities of water are annually evaporated through the foliage. These may be roughly estimated from the approximate data determined by v. Hönel*:—

Beech Forest.	Stems per Acre, averaging about	Gallons annually evaporated per Acre during Active Period of Vegetation.	Gallons requisite per Stem per diem.
115 years old -	200	450,000 to 540,000	11·02
50 to 60 years old -	520	260,000	2·20
35 years old -	1,600	70,000	0·22

By comparison of the development of trees of the same species, growing on soils of nearly equal quality, but in localities known to differ greatly as to the relative humidity of the air, it has been concluded that spruce, alder, maple, sycamore, and ash, and in a less degree silver fir, beech, and birch, thrive best in localities where the air has a high degree of relative humidity.

On the continent of Europe the principal tree on the dry sandy North German Plain is the Scots pine. Though it grows well in the damp insular climate of Britain, it does not thrive in the damp climate of Schleswig-Holstein. The spruce on the Harz, the beech on the Solling and Deister, and in a less marked

* Ramann's "*Forstliche Standortslehre*" in Lorey's "*Handbuch der Forstwissenschaft*," 1886, Vol. I., p. 301.

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degree the silver fir in Thuringia and on the highlands of Southern Germany, on account of their great transpiration through the foliage, thrive better in moist localities than in those more exposed to summer drought, and can often be reproduced there by sowing in the open without requiring nurses or parent standards as at lower elevations. In mountainous tracts snow-accumulations are apt to cause branches to snap off, so that brittle woods, like Scots pine, are not the species best adapted for forming forests there, whilst in localities exposed to violent winds shallow-rooted species, particularly spruce, are liable to become windfall.

2. *Aspect* is the exposure towards one or other of the points of the compass. It makes its influence felt chiefly with regard to warmth and soil-moisture. Any situation with southern or south-western aspect is much more exposed to the influence of the hot mid-day and afternoon sun than one facing the north or north-east. The soil in the former case is more apt to deteriorate, through becoming heated and deprived of its moisture by direct insolation, than in the latter; whilst at the same time transpiration through the leaves is stimulated to an excessive extent. On the other hand the limit of elevation to which a tree will ascend is reached sooner on the cool northern aspect. Western aspects are exposed to violent winds and heavy rain-storms; eastern exposures suffer most from frost.

3. *Gradient* is the angle formed by the surface of the soil with the horizontal. On steep slopes the production of timber is less than on those nearer the horizontal, although the soil-surface is actually larger, on account of the soil being generally shallower and less retentive of soil-moisture. Many situations, however, are well adapted for being utilised as woodlands, which are too steep for agricultural operations.

According to Grebe, gradients from 5° to 30° constitute the true home of forest growth. He classifies them from a sylvicultural point of view as:—

Gentle, 5–10°.
Medium, 11–20°.
Steep, 21–30°.
Very steep, 31–45°.
Precipitous, over 45°, which is, however, incapable of sustaining tree growth.

This classification has practically been adopted at the German experimental stations.

4. *Elevation above the Sea-level.*—Recent investigations made in the Bavarian Alps (Brenner Pass, 4,500 to 5,000 feet) have led

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to the following conclusions with regard to the effect of vertical elevation on the increment and the shape of forest trees *:—

A. *For individual Trees.*

1. Growth in height diminishes regularly and noticeably.
2. Growth in basal area, or sectional area of the stem at breast-height, does not diminish so rapidly as growth in height.
3. Total increment diminishes gradually.
4. The period of development is prolonged in all of the above three directions (*i.e.* the attainment of maturity is slower).
5. The bole or stem deviates more and more from the shape of the cylinder and approximates towards that of the neiloid.
6. The distribution of the increment over the various portions of the tree increases relatively from above downwards.
7. The form-factor at breast-height (*i.e.* the proportion which the actual volume of the stem bears to a cylinder having the same base) becomes smaller.
8. The coronal development gradually comes lower down, nearer to the ground (*i.e.* the stems become short and stunted).
9. The proportion of branches and brushwood increases (*i.e.* as the stems grow stunted, the coronal development increases relatively).

B. *For whole Crops.*

1. The number of stems per acre increases, but the proportion of those which form the larger girth-classes diminishes.
2. The mean average height of the crops diminishes.
3. The total basal area at breast-height does not diminish so perceptibly as the average height of the crops, but it is made up mostly by units belonging to the smaller classes of stems.
4. The total quantity of wood available as timber or fuel decreases perceptibly; hence the total average annual increment of the mature crop becomes considerably less.
5. The quantity of small branches and brushwood increases.
6. There is a decided tendency towards growth of the trees in groups instead of being equally distributed over the whole area.

* S. Honda, "*Ueber den Einfluss der Höhenlage der Gebirge auf die Veränderung der Zuwachses der Waldbäume*," 1892, p. 27.

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5. *Configuration of the Soil and the surrounding Country.*—The soils found in valleys, coombs, and dells, and along the base of uplands, is generally deeper, richer, and more productive than that on the ridges and shoulders of hills; but it is more exposed to dangers from frost in consequence of the air, when chilled by radiation, collecting within these low basins closed to the free play of currents of wind. Mountain masses have generally a more uniform standard of soil and situation than ranges of hills, on which the growth of woodlands is greatly influenced by the direction in which the ranges run. When the outermost ridge runs more or less at right-angles to the direction of the prevailing inauspicious winds, the inner ridges are protected; but when the unfavourable winds blow in the direction parallel to the ridges, they follow the windings of the valleys, and work injuriously along both slopes. The evil effects of want of protection from the winds can be easily noted in the vicinity of the sea-coast, or where plantations partially cover exposed hill-sides.

III.—Assessment of the Qualities of Sylvicultural Soils.

In treating of the description of soils and situations for sylvicultural purposes, it is well that there should be some recognised standard of quality, such as follows:—

No. I. = *very good* in quality.
No. II. = *good* in quality.
No. III. = *average or moderate* in quality.
No. IV. = *inferior* in quality.
No. V. = *poor* in quality.

This scale would, of course, only apply to each of the different species of timber crops *per se*; thus, for example, a soil properly classifiable as No. II. for a crop of Scots pine might only be assessable as No. III. for spruce or silver fir, or might perhaps rank even lower for beech, or oak, or other deciduous forests.

The classification could not, in fact, be in any degree absolute, but merely relative for the one particular species of forest tree.

In assessing the quality of forest soil for the purposes of framing a working-plan, past yield of mature timber is, when available, one of the most practical and ready means of determining the matter. But even when such information is not easily obtainable, the practised eye should find little or no difficulty in forming a tolerably correct and reliable estimate

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of this important factor towards the formation of a trustworthy plan of operations, without which no extensive forests can possibly be treated in the most rational and remunerative methods.

Complete and reliable yield-tables have not yet been framed for Scotland and England, but the following compilation from German sources may exhibit this mode of assessing the quality of the soil. Exclusive of timber extracted during thinnings, but including branches below 2·8 inches in diameter as well as timber, the total production of pure forest per acre has in Germany been found to be as follows (in cubic feet) :—

Age of Forest. Years.	Beech.		Silver Fir.		Spruce.		Scotch Pine.	
	Soil Quality.		Soil Quality.		Soil Quality.		Soil Quality.	
	I.	V.	I.	V.	I.	IV.	I.	V.
20	1,147	244	1,003	172	2,179	502	2,322	817
40	3,555	917	6,665	1,491	6,393	1,835	4,816	1,906
60	6,049	1,663	10,377	3,512	10,650	3,770	6,765	2,680
80	8,313	2,594	12,785	5,303	13,244	5,260	8,156	3,196
100	10,334	3,454	14,276	6,651	14,749	6,264	9,130	—
120	12,054	4,257	15,193	7,568	15,766	7,166	9,804	—

Thus, if a pure forest of spruce, grown in close canopy, normally well stocked, and regularly developed, has yielded about 5,260 cubic feet with a fall of 80 years, the soil is only assessable as of the IV. quality, or *inferior* for spruce; if, however, it may have yielded about 7,921 cubic feet it will be assessable as III. quality or *average*; if about 10,582 cubic feet as II. quality or *good*, by interpolating the II. and III. classes as about the arithmetical mean between the I. and IV., viz. :—

Quality.	I.	II.	III.	IV.
Cubic feet - -	13,244	10,582	7,921	5,260

But a tolerably correct estimate of the quality of the soil can also be obtained in growing crops from the determination of the average mean height of the crop, as the growth in height is more or less proportional to the general quality of the soil for sylvicultural purposes. It may be remarked that in pure woods of equal age, and growing in close canopy of normal density, the stems representing the average height of the crop fall in the class of the dominating, and not the predominating, poles or trees.

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In the tables formulated by Grebe,* but which are only approximately correct, and intended chiefly for the middle Saxon forests of Thuringia, the average mean height of timber-crops grown in pure forests is estimated as under :—

Kind of Forest.	Quality of Soil.	Age of Forest in Years, and Average Height in Feet.								
		40.	50.	60.	70.	80.	90.	100.	110.	120.
Beech.	I.	34	48	59	69	78	84	89	92	94
	II.	29	41	50	59	67	73	73	79	81
	III.	24	33	42	49	57	61	64	66	67
	IV.	19	27	33	40	44	48	50	51	52
Spruce.	I.	43	55	69	81	90	97	103	107	109
	II.	37	48	60	69	77	84	88	91	93
	III.	30	40	49	58	64	69	72	75	76
	IV.	23	30	39	45	50	54	57	58	—
	V.	16	21	27	32	36	39	40	—	—
Scots pine.	I.	39	52	65	75	84	90	95	98	99
	II.	36	47	58	67	73	79	83	85	86
	III.	31	41	49	57	62	66	68	70	—
	IV.	25	33	40	45	48	51	53	54	—
	V.	19	25	29	33	36	37	38	—	—

Thus a 60-year-old beech forest of 50 feet in average height would indicate that soil and situation are classifiable as of the II. quality. If the average height of an 80-year-old spruce wood is 60 feet, the soil may be put down as of the III. quality only. If a 55-year-old forest of Scots pine shows a mean average height of 45 feet the soil would also be reckoned as of the III. quality merely. These heights, however, refer to middle Germany, and will probably be found to exceed the average heights attainable in British forests, where planting has hitherto not usually been so close as to stimulate the upward growth to its fullest possible extent from the youthful period of development onwards.

* "*Die Betriebs-und Ertragsregelung*," 2nd edition, 1879, page 114.

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